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Weed Community Response to Crop Rotations in Western South Dakota

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Producers in the semiarid Great Plains are exploring alternative crop rotations, with the goal of replacing winter wheat–fallow. In 1993, a study was established to compare performance of eight rotations comprised of various combinations with winter wheat (W), spring wheat (SW), dry pea (Pea), safflower (Saf), corn (C), sunflower (Sun), proso millet (M), or fallow (F). After 8 years, we characterized weed communities by recording seedling emergence in each rotation. Seventeen species were observed, with downy brome, kochia, horseweed, and stinkgrass comprising 87% of the community. Rotations with the least number of weed seedlings were W–F and SW–W–C–Sun; in comparison, weed density was six-fold higher in W–M. Density of downy brome and kochia was highest in W–M compared with other rotations, whereas stinkgrass and green foxtail were prominent in proso millet of the W–M and W–C–M rotations. Horseweed established readily in safflower and dry pea. In the semiarid Great Plains, designing rotations in a cycle of four that includes cool- and warm-season crops can be a key component of integrated weed management.

Nomenclature: Downy brome, *Bromus tectorum* L. BROTE; green foxtail, *Setaria viridis* L. SETVI; horseweed, *Conyza canadensis* (L.) Cronq., ERICA; kochia, *Kochia scoparia* (L.) Schrad. KCHSC; stinkgrass, *Eragrostis cilinensis* (All.) E. Mosher ERACN; corn, *Zea mays* L.; dry pea, *Pisum sativum* L.; proso millet, *Panicum miliaceum* L.; safflower, *Carthamus tinctorius* L.; sunflower, *Helianthus annuus* L.; wheat, *Triticum aestivum* L..

Key words: Crop diversity, rotation design, BROTE, ERACN, ERICA, KCHSC, SETVI.

Cropping practices in the semiarid Great Plains are rapidly changing. Previously, winter wheat–fallow was the prevalent rotation used in this region. Fallow increases soil water levels in soil before planting winter wheat, thus reducing impact of erratic precipitation. A negative aspect of fallow, however, is loss of soil organic matter and declining soil health (Bowman et al. 1999). Fortunately, preserving crop residues on the soil surface minimizes the need for fallow because of increased precipitation storage during noncrop intervals (Farahani et al. 1998; Peterson et al. 1996). With herbicides replacing tillage to control weeds during fallow, more crop residues remain on the soil surface. Thus, producers are including crops such as corn, sunflower, and proso millet in their rotation and reducing frequency of fallow (Anderson et al. 1999).

With less-frequent fallow, however, weed densities have escalated rapidly in some rotations. Several factors may contribute to this trend, but producers believe that reducing the frequency of fallow is a key factor. Fallow helps weed management because producers can eliminate weed seed production during the fallow interval. Preventing weed seed production accentuates the natural decline of viable seeds in soil across time and reduces weed density in following crops.

In response to higher weed densities, producers changed crop management with increased seeding rates, competitive cultivars, fertilizer placement, or narrow row spacing to supplement herbicide efficacy with weeds (Anderson 2005; Valenti and Wicks 1992; Wicks et al. 1986). However, even with cultural practices supplementing herbicides, weeds are still prominent in croplands. Producers are seeking other strategies to compensate for minimizing the use of fallow and its impact on weed populations.

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One possible strategy to reduce weed community density is designing rotations with crops having different life cycles (Froud-Williams 1988). In western South Dakota, both cool- and warm-season crops are viable cropping options. Different planting and harvest dates among these crops provide opportunities for producers to prevent either plant establishment or seed production by weeds (Leeson et al. 2000; Streibig 1979). For example, green foxtail starts to emerge in mid-May, then begins flowering in late July. Because winter wheat is harvested in early July, producers can control green foxtail after winter wheat harvest, but before it flowers and produces seeds. A similar opportunity occurs with cool-season weeds such as downy brome; they can be controlled before planting warm-season crops such as corn or sunflower, thus preventing seed production.

Rotations that minimize weed community density may provide an additional benefit; some crops grown in the semiarid Great Plains, such as proso millet or annual forages, have few herbicide options to control weeds. Yet these crops are key components of the region's production systems. With lower weed density, yield and economic returns may improve with these crops. Also, crop diversity will help producers manage herbicide resistance by increasing the opportunities to rotate herbicides with different modes of action (HRAC 2005). Resistant weeds are common in this area (Heap 2005).

In 1993, Clair Stymiest established a rotation study with the goal of developing cropping systems that minimize frequency of fallow (Stymiest et al. 2001). Weed communities visibly differed among rotations after several years; thus, in the eighth cropping season, we characterized weed communities among the various rotations. Our goals were to quantify the changes in weed community densities among rotations, and to suggest guidelines for designing cropping systems that minimize both weed community density and the need for fallow as a weed management tactic.

Table 1. Weed seedling density of the weed community, downy brome, and kochia as affected by rotations at Wall, SD. Study was started in 1993 and weed community data were assessed in 2001.

Rotation[a]	Seedling emergence[b]		
	Weed community	Downy brome	Kochia
	plants/m^2		
W–F	33 a	5 a	14 b
W–M	225 e	143 d	46 a
W–C–M	65 bc	15 a	14 b
W–Saf–M	72 cd	22 a	8 b
W–Pea–M	60 bc	22 a	11 b
W–W–Saf–F	82 cd	55 b	8 b
W–W–Sun–F	94 d	82 c	4 b
SW–W–C–Sun	44 ab	15 a	13 b

[a] Abbreviations: W, winter wheat; F, fallow; M, proso millet; C, corn; Saf, safflower; Pea, dry pea; SW, spring wheat; and Sun, sunflower.

[b] Means within columns followed by an identical letter are not significantly different based on Fisher's protected LSD (0.05).

Materials and Methods

Study Design. The study was established in the fall of 1993 on a Nunn loam (Aridic Argiustoll) near Wall, SD. The soil contained 1.8% organic matter with pH 6.8. Yearly precipitation averages 440 mm. Eight rotations were compared (Table 1), comprised of various combinations of winter wheat, spring wheat, dry pea, safflower, corn, sunflower, and proso millet. With some rotations, fallow, a 10- to 14-mo noncrop interval that precedes winter wheat, also was included. Plot size was 10 $\times$ 17 m. The experimental design was a randomized complete block design with four replications. All phases of each rotation were present in each year.

Crop Management. Cultural tactics for each crop were considered best management practices for both crop management and weed suppression (Table 2). Cultivars commonly used by producers in the region were grown for each crop. Corn, safflower, and sunflower were planted in rows spaced 50 cm apart. Before these crops were planted, a liquid formulation of N and P fertilizer was injected 15 cm deep beneath the crop row at 50-cm row spacing.

Row spacing with winter wheat, spring wheat, dry pea, and proso millet was 25 cm. With the cereal grains, starter fertilizer of N and P at 7 kg N + 20 kg P/ha was banded on the soil surface by the crop row with the rest of N fertilizer applied broadcast during the tillering growth stage. The N and P fertilizer level for all crops was based on projected nutrient needs, determined by soil sampling and target yield goals. Dry pea was inoculated with *Rhizobium* spp. in a granular formulation to facilitate N_2 fixation.

Tillage. Plots were established with minimum tillage to preserve crop residues on the soil surface. Tillage occurred only when fertilizers were injected in soil with crops grown in 50-cm row spacing, and when sweep plowing was used to control weeds during fallow preceding winter wheat. Small grains were planted with a drill having hoe openers, resulting in some soil disturbance at planting.

Weed Management. Weed management tactics in the study were similar to practices followed by producers in the region. Winter wheat and spring wheat were treated with metsulfuron + 2,4-D applied POST at 0.005 + 0.5 kg ai/ha. With safflower, dry pea, and sunflower, granular trifluralin was applied at 1.3 kg ai/ha in November, relying on winter precipitation to incorporate the herbicide. In addition, sethoxydim was applied POST at 0.2 kg ai/ha to control grasses in dry pea and safflower whereas sulfentrazone was applied PRE at 0.14 kg ai/ha after planting sunflower.

To control weeds in corn, atrazine at 1.1 kg ai/ha was applied 4 wk after winter wheat harvest, followed by nicosulfuron applied POST at 14 g ai/ha. During 1999 through 2001, glyphosate at 0.6 kg ae/ha replaced nicosulfuron for the POST control tactic in a glyphosate-resistant hybrid. To control weeds in proso millet, atrazine was applied at 1.4 kg/ha in October, 8 mo prior to planting the next year.

Glyphosate applied POST at 0.6 kg/ha controlled weeds present at planting in corn, sunflower, and proso millet. With crops planted in early spring, such as dry pea or safflower, glyphosate was not applied at planting because weeds were either dormant or seedlings had not emerged. After winter wheat harvest, glyphosate was applied in November to control winter annual weeds. During fallow, weeds were controlled with two tillage operations with a sweep plow, followed by glyphosate applied as needed. Weeds present during noncrop intervals of continuous cropping rotations were controlled with glyphosate applied as needed.

Weed Community Assessment. Weed flora and seedbank densities were assessed in all rotations during 2001, the eighth cropping season. For seedbank analysis, 10 soil cores, 10 cm in diameter and 15 cm deep, were collected and composited in the fall of 2001. Sampling sites were arranged in a W

Table 2. Management practices for various crops grown in the rotation study at Wall, SD. Planting and harvesting dates represent the time interval when operations occurred, 1993–2001. Cultivars listed were grown in 1999–2001.

Crop	Cultivar	Planting date	Seeding rate (seeds/ha)	N management	Harvest date
Winter wheat	'Tandem'	September 10–25	2.9 million	Starter + broadcast in-crop	July 10–20
Spring wheat	'Forge'	March 25–April 1	2.9 million	Starter + broadcast in-crop	July 20–August 1
Dry pea	'Grande'	March 25–April 1	740,000	None	July 20–August 1
Safflower	'S-541'	April 5–15	520,000	Inject in soil, 15 cm deep, at 50 cm spacing	September 1–10
Corn	'DK-493RR'	April 28–May 15	48,400	Inject in soil, 15 cm deep, at 50 cm spacing	October 1–15
Sunflower	'Cargill' SF270A	May 20–June 1	48,400	Inject in soil, 15 cm deep, at 50 cm spacing	October 5–20
Proso millet	'Sunup'	June 1–10	2.7 million	Starter + broadcast in-crop	August 20–30

Table 3. Weed species observed in the study and abundance of each species in the weed community, averaged across all rotations.

Weed species			
Common name	Scientific name	WSSA code	Percent of weed community
Downy brome	*Bromus tectorum L.*	BROTE	51
Kochia	*Kochia scoparia* (L.) Schrad.	KCHSC	21
Horseweed	*Conyza canadensis* (L.) Cronq.	ERICA	10
Stinkgrass	*Eragrostis cilianensis* (All.) E.Mosher	ERACN	6
Green foxtail	*Setaria viridis* (L.) Beauv.	SETVI	3
Prickly lettuce	*Lactuca serriola* L.	LACSE	3
Russian thistle	*Salsola iberica* Sennen & Pau	SASKR	2
Dandelion	*Taraxacum officinale* Weber in Wiggers	TAROF	1
Wavyleaf thistle	*Cirsium undulatum* (Nutt.) Spreng.	CIRUN	1
Lanceleaf sage	*Salvia reflexa* Hornem.	SALRE	<1
Tumblegrass	*Schedonnardus paniculatus* (Nutt.) Trel.	SCEPA	<1
Waterpod	*Ellisia nyctelea* L.	ELSNY	<1
Pinnate tansymustard	*Descurainia pinnata* (Walt.) Britt.	DESPI	<1
Prostrate knotweed	*Polygonum aviculare* L.	POLAV	<1
Common mallow	*Malva neglecta* Wallr.	MANLE	<1
Wild buckwheat	*Polygonum convolvulus* L.	POLCO	<1
Redroot pigweed	*Amaranthus retroflexus* L.	AMARE	<1

pattern across the plot, with sampling sites 2 m apart. Procedures used to quantify weed seedling densities in greenhouse trials followed Forcella (1992).

For weed flora, a 1-m^2 quadrat was placed in the center of each plot; the quadrat was covered with plastic when herbicides were applied for crop management. Weed seedlings were counted and identified May 1 (cool-season weeds) and August 1 (warm-season weeds). After counting, weeds were removed by hand.

Treatment effects were similar between weed flora and seedbank data, with one exception; redroot pigweed was observed only in seedbank samples. Therefore, only weed flora data are presented, with the redroot pigweed seedbank data discussed in the text. Six species comprised more than 90% of the weed community, with downy brome and kochia being the most prominent (Table 3). In 1993, these two species also were the most prevalent weeds infesting the site.

Statistical Analysis. Weed flora densities are the sum of both assessment dates, and were analyzed by ANOVA. Community density was compared among all rotations, with density values averaged across all crops within a rotation. Individual species were analyzed only among rotations where the species was observed. Treatment means were separated with Fisher's protected LSD at the 0.05 level of probability.

Results and Discussion

Weed Community Response. Seedling emergence in W–F was 33 plants/m^2; in contrast, 225 seedlings emerged in W–M, a seven-fold increase (Table 1). Weed density in the four-crop rotation, SW–W–C–Sun, was similar to W–F, whereas weed density in the three-crop rotations, W–C–M, W–Saf–M, and W–Pea–M, was approximately two-fold greater than with W–F. Comparing four-year rotations, seedling density was two-fold greater in W–W–Sun–F and W–W–Saf–F than with SW–W–C–Sun. Differences in weed community density among rotations often reflected individual species response to specific rotations.

Individual Species Response. *Downy brome.* Weed management for this study did not include herbicides to control downy brome; thus, downy brome densities reflected rotation design. Five downy brome plants/m^2 were observed in W–F; in contrast, downy brome density in W–M was almost 30-fold greater (Table 1). When winter wheat was grown only once every 3 or 4 yr in a rotation, downy brome density was similar to W–F. However, when winter wheat was grown 2 yr in a row, as with W–W–Sun–F and W–W–Saf–F, downy brome density increased 11- to 16-fold compared with W-F.

We attribute increased density of downy brome in W–M compared with W–F to suppressed winter wheat growth in W–M. Yield of winter wheat in W–F was 3850 kg/ha, whereas yield in W–M was 35% less (Stymiest et al. 2001), which we attribute to less soil water available for winter wheat growth in W–M. The suppressed canopy development of winter wheat in W–M likely favored seed production of downy brome. Other research has shown that downy brome productivity is higher in less-developed crop canopies (Anderson 1997). Winter wheat yield was also low following proso millet in W–C–M, W–Saf–M, and W–Pea–M, but the natural seed loss of downy brome in the seedbank during the 2-yr interval before the next winter wheat crop suppressed population growth of downy brome. Growing winter wheat 2 yr in a row with W–W–Sun–F and W–W–Saf–F favored seed production by downy brome, thus minimizing the benefit of the 2-yr interval of oilseed crop and fallow on downy brome seedbank dynamics.

Kochia. Plants of kochia were observed in all rotations, but most prominently in W–M (Table 1). As with downy brome, we attribute population growth of kochia in W–M to winter wheat being less competitive following proso millet. Kochia starts emerging in April (Wicks and Smika 1990); reduced growth of winter wheat with W-M allowed kochia infesting the crop to produce more seeds. With other rotations, diversity of crops or fallow suppressed population growth of kochia.

Warm-season grasses: stinkgrass and green foxtail. Seedlings of these species emerge in May and June and start flowering in

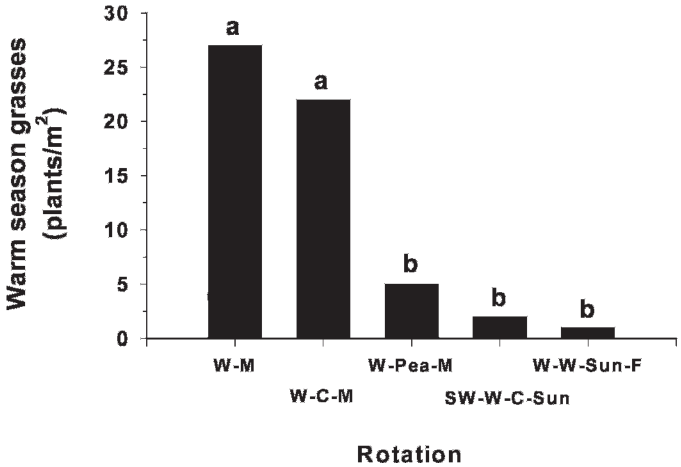

Figure 1. Impact of rotation on density of green foxtail and stinkgrass after 8 years at Wall, SD. These species were analyzed only among rotations where the species was observed. Bars with identical letters are not significantly different based on Fisher's protected LSD (0.05). Abbreviations: C, corn; F, fallow; Pea, dry pea; Saf, safflower; Sun, sunflower; and W, winter wheat.

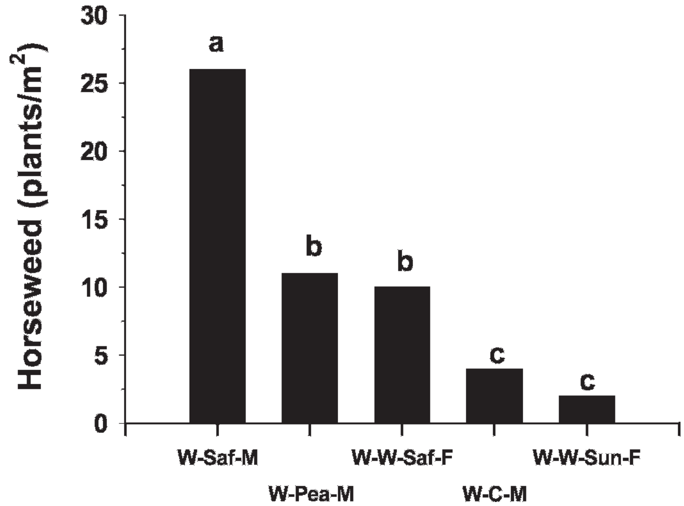

Figure 2. Density of horseweed among five rotations after 8 years at Wall, SD. Horseweed density was analyzed only among rotations where horseweed was observed. Bars with identical letters are not significantly different based on Fisher's protected LSD (0.05). Abbreviations: C, corn; F, fallow; Pea, dry pea; Saf, safflower; Sun, sunflower; and W, winter wheat.

late July (Wicks and Smika 1990). Because these grasses responded similarly to rotations in our study, we combined data of these species. Density was highest with W–M and W–C–M (Figure 1), which we attribute to management tactics not controlling grasses effectively in proso millet. However, adding a second cool-season crop to the rotation, W–Pea–M, reduced density of these species considerably; density was more than four-fold greater in W–M or W–C–M compared with W–Pea–M. The 2-yr interval in cool-season crops minimized population growth that occurred in W–M or W–C–M.

A similar trend occurred with SW–W–C–Sun, where density of these species was 2 plants/m^2, or 90% less compared with W–M (Figure 1). Some plants of these grasses may have escaped control in corn and sunflower, but the 2-yr interval without seed production in SW and W suppressed population growth.

Horseweed. Horseweed was most prominent in W–Saf–M, W–Pea–M, and W–W–Saf–F (Figure 2). In contrast, horseweed was not observed with W–F and SW–W–C–Sun (data not shown). This species emerges either in the fall or spring (April and May), then begins flowering in July (Wicks and Smika 1990). The growth period of horseweed coincides with safflower and dry pea (Table 2); thus plants were able to establish and produce seeds. With corn, sunflower, and proso millet, horseweed seedlings were controlled with glyphosate before planting, thus minimizing seed production in these crops and suppressing population growth.

Redroot pigweed. This species was rarely observed in field sampling, but seedlings were prominent in seedbank samples. Environmental conditions in 2001 may not have been favorable for redroot pigweed seedling emergence in the field.

With seedbank data, redroot pigweed was most prominent in W–M, W–Saf–M, and W–W–Saf–F (data not shown). Seedling numbers were highest in samples collected in proso millet and safflower plots. Because redroot pigweed seedlings emerge from May through early July (Wicks and Smika 1990), ineffective management tactics in proso millet and safflower allowed redroot pigweed to establish and produce seeds. In contrast, redroot pigweed was effectively controlled in corn and sunflower, other crops with similar growth periods to redroot pigweed.

Weed community diversity. Integrating crops with different life cycles in a rotation leads to diversity of the weed community and minimizes the predominance of any one species (Froud-Williams 1988). In our study, downy brome and kochia comprised more than 90% of the weed community with W–M (Figure 3). In contrast, the weed community in SW–W–C–Sun was more diverse, with eight species—kochia, green foxtail, Russian thistle, wild buckwheat, annual sowthistle, redroot pigweed, and common lambsquarters—comprising 91% of the seedlings observed. With W–M, density of downy brome was greater than the total weed community density in SW–W–C–Sun.

Booth and Swanton (2002) suggested that less weed population oscillation would occur with weed communities comprised of a diversity of species. In western South Dakota, producers have experienced vast oscillations with density of downy brome in W–F; we suggest that similar oscillations will occur with W–M. In contrast, low density of individual species with SW–W-C-Sun may minimize population oscillations with this rotation.

Insight for Designing Semiarid Rotations. Producers are concerned that eliminating fallow in rotations will favor population growth of the weed community. However, weed densities did not increase with SW–W–C–Sun, a rotation comprised of two cool-season crops followed by two warm-season crops, compared to W–F (Table 1). In contrast, weed populations increased with shorter rotations such as W–M or W–Saf–M. A similar trend occurred with short rotations in western Canada; weed community density increased across time with W–canola (*Brassica campestris* L.) or W–lentil (*Lens culinaris* L.) compared with W–F (Blackshaw et al. 1994).

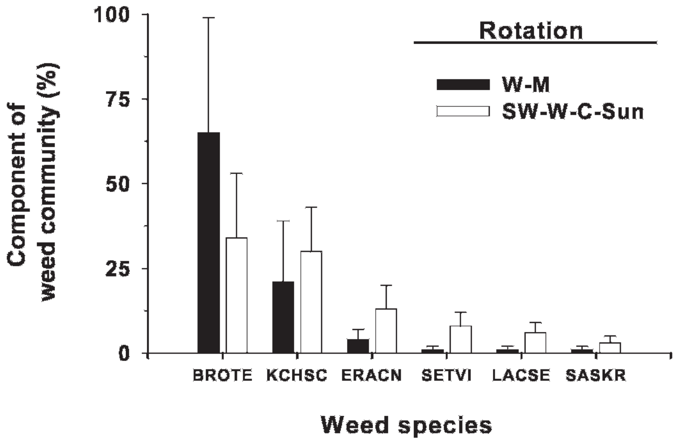

Figure 3. Diversity of the weed community, comparing W–M with SW–W–C–Sun. Weed community assessed in the eighth year of the study at Wall, SD. The vertical line above each bar represent the standard error of the mean. Weeds are identified by WSSA code: BROTE, downy brome; KCHSC, kochia; ERACN, stinkgrass; SETVI, green foxtail; LACSE, prickly lettuce; SASKR, Russian thistle. Abbreviations: C, corn; M, proso millet; Sun, sunflower; SW, spring wheat; and W, winter wheat.

Holtzer et al. (1996) recommended that weed management tactics be integrated with cropping systems design. Based on our study, we suggest that arranging cool- and warm–season crops in a cycle of four will suppress population growth of weed communities in western South Dakota, as noted with SW–W–C–Sun. Producers in northeastern Colorado who follow this rotation design have reduced weed community density in their fields such that some crops do not need herbicides for in-crop weed control (Anderson 2000). Derksen et al. (2002) reported a similar trend in Canada; rotations comprised of four different crops varied selection pressure on the weed community and prevented population growth across time.

An additional tactic that may help producers manage weeds is combining rotations. For example, horseweed was prominent in W–Saf–M but not in W–C–M. Combining these rotations to form a 6-yr sequence may suppress population growth of horseweed. A similar approach may help manage stinkgrass and green foxtail, which proliferated in W–C–M but not with W–Pea–M.

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